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TECHNICAL REPORT EL-89-10

SPECIES PROFILES: LIFE HISTORIES AND ENVIRONMENTAL REQUIREMENTS OF COASTAL VERTEBRATES AND INVERTEBRATES PACIFIC OCEAN REGION

Report 2

HUMPBACK WHALE, *MEGAPTERA NOVAEANGLIAE*

by

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National Oceanic and Atmospheric Administration
Honolulu, Hawaii 96822-2396

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world. The major environmental impact facing humpback whales in Hawaiian waters is the loss and modification of shallow nearshore habitat to harbor, resort, and other coastal development, and the subsequent increase in human activity including vessel traffic, which may result in disturbance and displacement of humpback whales from preferred habitat.

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PREFACE

This report was published as part of the Environmental Impact Research Program (EIRP), sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). Partial funding was provided by the US Army Engineer District, Honolulu. Technical Monitors were Dr. John Bushman, Mr. David P. Buelow, and Mr. Dave Mathis of HQUSACE. Dr. Roger T. Saucier, Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), was EIRP Program Manager.

This report is designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the humpback whale, *Megaptera novaeangliae*, and to describe how populations of the species in the Hawaiian waters may be expected to react to environmental changes caused by coastal development. The report has sections on taxonomy, life history, ecological role, environmental requirements, growth, exploitation, and management. The report was prepared by Messrs. Eugene T. Nitta and John J. Naughton of the Southwest Region, National Marine Fisheries Service (NMFS), under support agreement WESCW88-241.

Dr. C. Scott Baker, National Cancer Institute, Department of Health and Human Services; Dr. James D. Darling and Ms. Elizabeth Mathews, West Coast Whale Research Foundation, Vancouver, B.C.; Dr. Dale Rice and Ms. Sally Mizroch, National Marine Mammal Laboratory, NMFS; Dr. Gerald Scott, Miami Laboratory, Southwest Fisheries Center, NMFS; and Mr. Michael T. Lee, US Army Engineer District, Honolulu, provided reviews of the manuscript. Mr. Allan Wolman, National Marine Mammal Laboratory, NMFS, and Dr. Darling provided additional unpublished data.

Mr. Edward J. Pullen, Coastal Ecology Group, EL, served as Contract Monitor for this study under the general supervision of Dr. Conrad J. Kirby, Chief, Environmental Resources Division, EL, and Dr. John Harrison, Chief, EL, WES.

COL Larry B. Fulton, EN, was Commander and Director of WES.
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CONVERSION TABLE

Metric to U.S. Customary

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m ²)	10.76	square feet
square kilometers (km ²)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m ³)	35.31	cubic feet
cubic meters (m ³)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft ²)	0.0929	square meters
square miles (mi ²)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft ³)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

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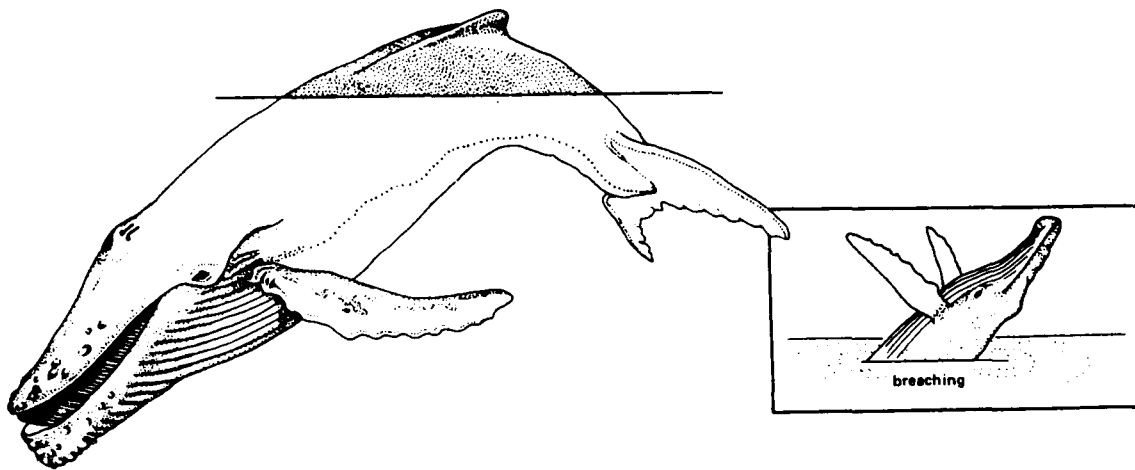


Figure 1. Humpback whale
(Northwest Fisheries Center, National Marine Fisheries Service)

THE NORTH PACIFIC HUMPBACK WHALE IN HAWAIIAN WATERS

NOMENCLATURE, TAXONOMY, AND RANGE

Scientific name.....Megaptera
novaeangliae (Borowski, 1781)
Preferred common name Humpback
whale (Figure 1)
Other common names .. Humpbacked whale
Class Mammalia
Order Cetacea
Suborder Mysticeti
Family Balaenopteridae

Geographic range: Worldwide. In the North Pacific, winters in shallow nearshore waters of usually 100 fathoms or less around the Ryukyu and Bonin Islands of Japan and Taiwan in the western North Pacific; main Hawaiian Islands in the central North Pacific; the coast and off-

shore islands of central Baja California to Cabo San Lucas and the southern Gulf of California; and off mainland Mexico from Sonora to Jalisco, and the Revillagigedo Islands (Socorro, San Benedicto, and Clari6n). Distribution over the summer feeding grounds ranges from the coasts of Honshu, Japan, and southern California north to the Chukchi Sea (for distribution in the Hawaiian Archipelago, see Figure 2).

MORPHOLOGY AND IDENTIFICATION

Humpback whales are medium-sized rorquals, with adult females larger (average = 14 m) than males (average = 13 m). In comparison with other balaenopterids such as fin whales

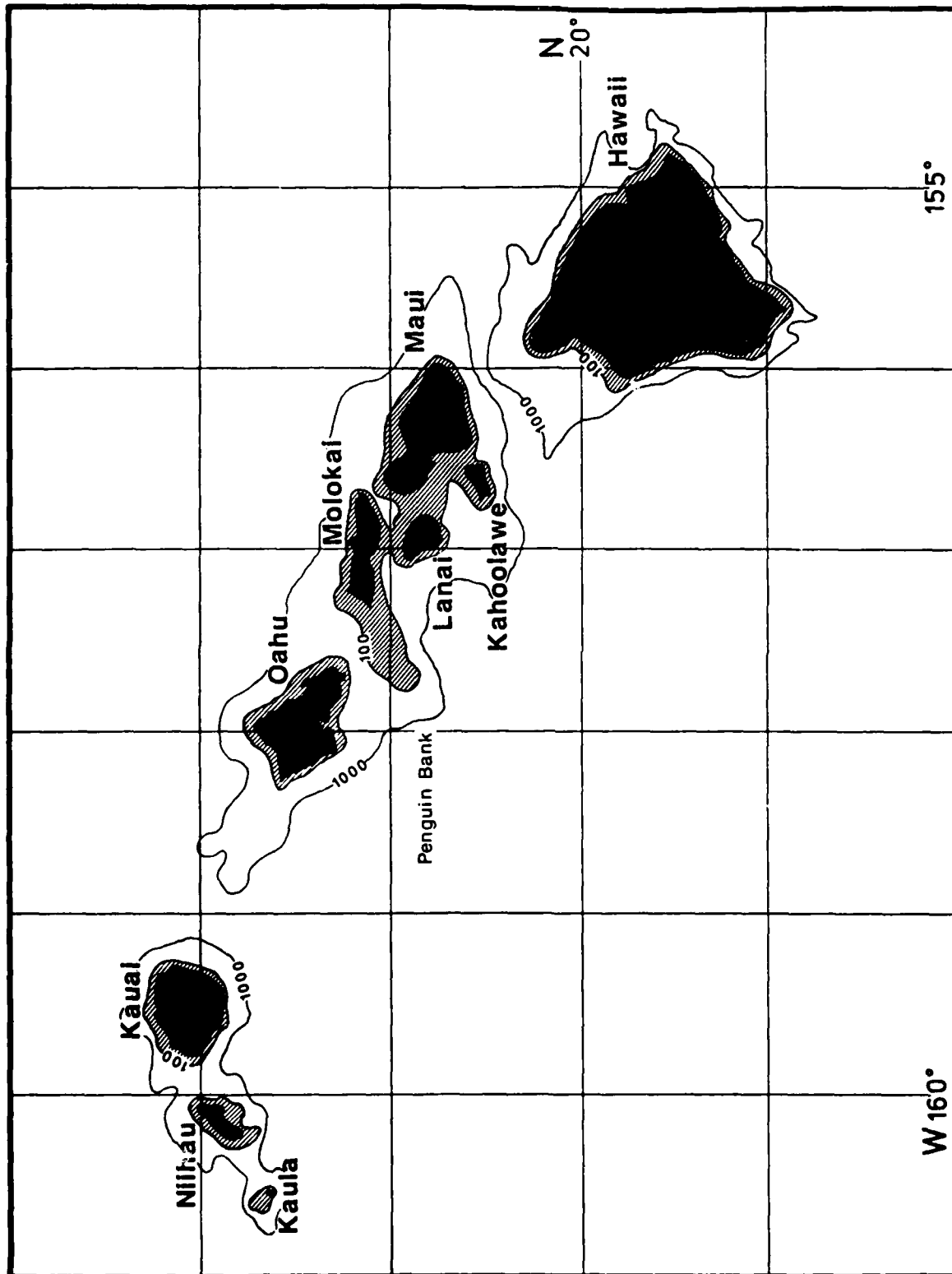


Figure 2. Distribution of humpback whales in Hawaiian waters (depths in fathoms).

(Balaenoptera physalus) or sei whales (B. borealis), humpback whales are more full-bodied (Leatherwood and Reeves 1983). When viewed from above, the head is broad, much like that of a blue whale (B. musculus). The dorsal aspect of the head is distinctive with a number of fleshy knobs or tubercles distributed from the tip of the snout to the blowhole and along the sides of the lower jaws. Each one of these fleshy knobs supports at least one tactile hair. In lateral view, the head is surprisingly slim and can resemble an alligator in profile. Paired blowholes are characteristic of baleen whales, and the humpback whale's pear-shaped blow reaches heights of 2 m or higher.

The long flippers are characteristic of humpback whales, measuring nearly one-third the length of the body; the front edge bears a series of knobs and is irregularly scalloped. Ventral grooves, which number from 14 to about 22, extend from the chin to the navel (Leatherwood et al. 1982). The dorsal fin is located less than one-third of the body length from the fluke notch and slightly behind the intersection of the anus (Nishiwaki 1972). It is relatively small and ranges from a distinct falcate fin to a small triangular nubbin. The dorsal fin is often associated with a step or hump which is accentuated when the animal dives, from which the animal derives its common name (Leatherwood and Reeves 1983). The width of the flukes are one-third the total body length and are serrated or scalloped along the trailing edge. Coloration of the dorsal aspect of the flukes is usually dark. The flukes' ventral surface ranges from completely black to almost totally white, with numerous scar patterns and other natural markings allowing identification of individual animals over time.

Humpback whales are basically dark gray to black. The ventral surface is variably white, with a white

patch along the ventral midline to the anus. The undersides of the flippers are always white; the upper surface varies from mostly black to white (Leatherwood and Reeves 1983).

The relatively short baleen plates number from 270 to 400 and are generally blackish with gray fringes.

The vertebral formula is $C7 + T14 + L10 + Ca21-22 = 52-53$. The flippers have four fingers of I: 2, II: 7, IV: 6, V: 3 (Nishiwaki 1965, 1972).

REASON FOR INCLUSION IN SERIES

The coastal habitat of the humpback whale made it one of the most vulnerable species to modern whaling. Overexploitation resulted in the worldwide depletion of most stocks of humpback whales. The International Whaling Commission (IWC) banned the commercial harvest of humpback whales in the North Atlantic in 1955, the North Pacific in 1965, and the Southern Hemisphere in 1966. In 1970 humpback whales were listed as an endangered species under the Endangered Species Conservation Act of 1969. All stocks of humpback whales remain listed as endangered under the Endangered Species Act of 1973, as amended.

The wintering grounds of some stocks lie within the territorial waters of non-IWC member countries, and a few animals are taken annually in aboriginal hunts. Humpback whales are also increasingly subject to seabed mining and oil and gas recovery activities, nearshore pollution, ocean dumping, entanglement in fishing gear, coastal and tourist-related development such as marinas, harbors, and resorts, and vessel traffic. These factors affect competition for and the availability of prey resources, and habitat availability. Each activity has the potential for direct disturbance (i.e., harassment) of individual whales or an indirect impact through damage to habitat or both.

Although humpback whales are protected from direct exploitation on a large scale, population estimates remain uncertain and low, and recovery rates are unknown. Furthermore, the species' dependence on coastal habitats for calving, rearing, courtship, and feeding suggest that recovery may be negatively affected by the continuing degradation of these habitats. Habitat loss and modification can have a particularly acute impact in coastal wintering grounds associated with islands or island groups such as Hawaii, where preferred humpback whale habitat is limited and displacement into suboptimal areas may occur due to extensive human activities.

LIFE HISTORY AND ECOLOGY

Reproduction and Recruitment

Age at sexual maturity for both male and female humpback whales has been estimated from 5 years (Nishiwaki 1959; Chittleborough 1965) up to 9 years (Johnson and Wolman 1984). Glockner-Ferrari and Ferrari (1987) report a known-age male of 7 years actively participating in apparent courtship behavior in Hawaii. More recently Clapham and Mayo (1987) report known-age females with calves at 4 and 6 years, respectively, observed in Massachusetts Bay (Gulf of Maine), inferring age at sexual maturity at 3 and 5 years for these individuals. Nishiwaki (1965) reported length at sexual maturity for females at 11.4 - 12.0 m, and 11.1 - 11.4 m for males.

As seasonal breeders, humpback whales have reproductive cycles that are closely tied to their seasonal migrations. Mature females are believed to conceive on the breeding grounds one winter and give birth the following winter. Gestation lasts about 12 months. A few known females have produced a calf in successive years on the Hawaiian wintering grounds (Glockner-Ferrari and Ferrari

1987), but the usual reproductive cycle appears to be 2 or more years. Chittleborough (1958) examined Norwegian Antarctic whaling records for females selectively taken in commercial whaling operations from 1950 to 1955. He noted that 8.5% of the sexually mature females were both pregnant and lactating and, thus, must have mated shortly after giving birth. The survival rate of calves from annual breeders is not known.

In the Northern Hemisphere births usually occur between January and April. Calves are about 4 m to 5 m long at birth and colored light gray (Chittleborough 1958; Nishiwaki 1959; Leatherwood and Reeves 1983). The single calf is nursed for 10 to 11 months and is about 8 to 9 m long at weaning after completing one migration to the summer feeding grounds with its mother.

Estimates of calving rates for Hawaii range from 0.29 to 0.58 (calves per mature female per year) on the basis of resighting data and aerial survey data (Herman and Antinof 1977; Baker, Perry, and Herman, in press). Baker, Perry, and Herman in press suggest that an overall calving rate of 0.37 for the Hawaiian population is most accurate, with mature females averaging every 2.7 years the birth of a calf that survives its first 6 months of life and its first migration. Forestell (in prep.) found that of 347 whales sighted between January and April 1985, 35 (10%) were calves.

Mating Behavior

Humpback whale behavior on the Hawaiian wintering grounds strongly suggests that both calving and mating occur in or near these waters. Analysis of ovaries and testes from humpback whales taken in commercial whaling operations (Chittleborough 1958) and estimates of the length of gestation indicate that the months of assembly in Hawaii include the peak of the mating period. Though neither

calving nor mating has actually been observed, cows with very young calves are commonly sighted in shallow, near-shore, protected waters less than 10 fathoms in depth and often very close to shore or the outer reef. Aggressive and apparent agonistic behavior among males presumably for access to potentially receptive females, and pairing and consort behavior between males and females have been detailed by Baker, Herman, and Stifel (1981); Darling (1983); Tyack and Whitehead (1983); Baker and Herman (1984); and Glockner-Ferrari and Ferrari (1985). Females probably come into estrus within a 3- to 4- month period while wintering in Hawaiian waters (Darling 1983). Cuts and abrasions are inflicted by males on each other, with head butts, flipper slaps, peduncle slaps, breaches, and other aggressive behaviors during competition for access to females (Baker and Herman 1984; Johnson and Wolman 1984).

Commonly observed group or unit compositions on the winter grounds include: cow with calf, often escorted by a male; lone singers (males); lone adults; pairs of adults (male-male, male-female); and larger groups (multiple males and a female). There is a regular interchange of individuals between and among these groups that occurs over hours or days, except for cow-calf pairs (Mobley and Herman 1981; Baker and Herman 1984; Mobley and Herman 1985; J.D. Darling, 1988, West Coast Whale Research Foundation, Vancouver, B.C., pers. commun.)

Vocalizations

On the winter breeding grounds, humpback whales produce "songs" which have been described as a series of repeating, complex sequence of sounds including whistles, chirps, squeals, and grunts organized into phrases or syllables within a phrase (Payne, Tyack, and Payne 1983). The frequency range of these songs is generally less than 4 kHz (Payne and McVay 1971; Thompson, Winn, and Perkins 1979;

Payne and Guinee 1983). A number of singers have been identified as males, and it has been hypothesized that, among other uses, these humpback whale songs function as acoustic displays demonstrating dominance (Darling 1983; Darling and Morowitz 1986) and/or availability (Tyack 1981; Baker and Herman 1984). Some males also remain longer on the breeding grounds than other males and females, suggesting that they may be dominant males staying as long as females come into estrus (Darling 1983).

"Social sounds" are nonsong vocalizations produced on the winter breeding grounds and are thought to be associated with agonistic behavior within large, surface active pods of humpbacks. These social sounds do not possess the complex structure of songs with their peak energy between 1- to 3-kHz and the frequency range usually below 4.7 kHz (Tyack 1983; Mobley, Herman, and Frankel 1986; Silber, in press; A. Frankel, 1988, Kewalo Basin Marine Mammal Laboratory, University of Hawaii, pers. commun.).

A third type of stereotyped vocalization, the "feeding call," has been recorded during the summer months in the vicinity of feeding whales in southeastern Alaskan waters (Baker 1985). It is described as a "highly stereotyped series of trumpeting calls, each of approximately 2 sec in length, with a frequency range of 440 to 550 kHz" (Baker 1985; Mobley, Herman, and Frankel 1986).

Natural Mortality

Mizroch (1985) notes natural mortality estimates for North Pacific humpback whales of 0.05 - 0.08 as reported by Ohsumi (1979) from Doi, Nemoto, and Ohsumi (1967). Neither the method of estimation nor sample size was reported.

Large sharks, such as great whites (Carcharodon carcharias) and tigers (Galeocerdo cuvieri), and kill-

er whales (Orcinus orca) are probably responsible for a large proportion of the natural mortality of calves and old or ailing adults. Large tiger sharks were observed consuming a humpback whale calf near Molokini Island. Whether the sharks killed the calf first or were just feeding on the carcass was not determined (Shallenberger 1981). During the Cooperative Shark Research and Control Program conducted by the University of Hawaii around the Hawaiian Islands in 1967-69, 6% of the tiger sharks caught had large whale and small odontocete remains in their stomachs (Tester 1969).

In higher latitudes, humpback whales that frequent the edge of ice fields are sometimes trapped in the ice. (Lien et al. 1983).

In late 1987 and early 1988, a large number of mysticete whales died and came ashore in the Cape Cod area. A total of 15 humpback whales, 4 minke whales (Balaenoptera acutorostrata), and 2 fin whales (B. physalus) were included in this episode. Testing of mackerel found in the stomachs of the animals sampled showed the presence of a toxin with effects similar to that of paralytic shellfish poison biotoxins. This is the first instance in which a biotoxin has been implicated in large whale mortality (D.W. Beach, 1988, Northeast Region, National Marine Fisheries Service, pers. commun.).

Ectoparasites and Commensals

Although humpback whales are infested with various ectoparasites and commensals, they rarely manifest a debilitating reaction. Barnacles are large and conspicuous over certain parts of the body. They tend to concentrate along areas of high turbulence, such as the flukes, the leading edge of the dorsal fin and flipper, or along the midline of the ventral pleats. Smaller whale lice (cyamid crustaceans) are distributed around

barnacles and in depressions and folds in the skin. Cookiecutter sharks (Isistius spp.) and lampreys cause some skin and blubber damage which probably result in some scarring.

Accidental Mortality

Humpback whales can become entangled in various types of fixed fishing gear, including fish weirs and traps, lobster trap lines, buoy lines, and gill and trammel nets. These incidents have occurred mainly off the northeastern United States and eastern Canada, and most injuries and mortalities are reported from these areas (Perkins and Beamish 1979; Lien and Aldrich 1982; Lien et al. 1982; Lien et al. 1983; Lien, Walter, and Harvey-Clark 1985; T. MacKenzie, 1989, Northeast Region, National Marine Fisheries Service, pers. commun.)

Another source of injuries and accidental mortalities are collisions with vessels. Since 1986, a near miss and two collisions have been documented in Hawaiian waters (Siler 1987; Stevens 1988; Tanji 1988). Collisions are likely to occur with greater frequency where high speed vessel traffic is increasing in areas of high whale concentrations, such as off the leeward coast of Maui and to a lesser extent off Kailua-Kona on the Island of Hawaii and the south shore of Oahu.

Feeding

Summer feeding areas occur across the Pacific, from the Aleutian Islands to the Farallon Islands off central California. In the Northern Hemisphere the diet of humpback whales consists of pelagic organisms of the coastal zone. These include mainly krill (euphausiids) along with schooling fishes such as herring, Clupeidae; sand lance, Ammodytes sp.; capelin, Mallotus villosus; juvenile salmonids, Onchorhynchus spp.; Arctic cod, Boreogadus saida; walleye pollock, Pollachius virens; and anchovies, Engraulis mordax; rarely cope-

Pods, pteropods and cephalopod mollusks (Wing and Krieger 1983, unpub. manuscript, Auke Bay Laboratory, National Marine Fisheries Service, NMFS, Auke Bay, AK; Johnson and Wolman 1984; Krieger and Wing 1984). Humpback whales are found to be heavily clumped in their distributions relative to prey abundance (Johnson and Wolman 1984).

Isolated incidents of apparent feeding and observations of defecation by humpback whales have been noted in Hawaii. Schooling carangids (Opelu, Decapterus macarellus and akule, Selar crumenophthalmus) occur in large aggregations within Hawaiian waters frequented by humpback whales; however, there have been no confirmed sightings of humpback whales feeding on these potential prey species. Humpback whales are not known to regularly feed in Hawaiian waters (Glockner-Ferrari and Ferrari 1985).

Humpback whales feed at the surface down to about 150 m (Dolphin 1987). Feeding techniques have been described as skimming, lunge feeding, and circular swimming (Jurasz and Jurasz 1979). Bubble net feeding is an interesting behavior in which a submerged whale releases a stream of bubbles in patterns ranging from lines and partial circles to complete circles with "tails." The animal then rises through the concentration of prey with its mouth open. Various levels of apparent cooperation during bouts of feeding have also been observed, including herding of prey (Baker and Herman 1985).

EXPLOITATION AND POPULATION SIZE

History of Exploitation

An unknown number of humpback whales were taken by aboriginal hunters and commercial whalers prior to 1900 in the North Pacific. During the course of modern whaling from 1905 to 1960 in the eastern Pacific and 1889

to 1960 in the western Pacific, approximately 23,000 humpbacks were taken. Between 1960 and 1965, more than 5,000 were killed in commercial whaling operations reducing the North Pacific population to about 1,000 (Rice 1978).

Current and Initial Stock Sizes

The preexploitation size of the North Pacific population of humpback whales prior to 1905 was estimated to be about 15,000 animals (Rice 1978). A recent estimate of the North Pacific population of 2,100 is based on a mark and recapture estimate derived from individual sightings of animals over a 4-year period (Darling and Morowitz 1986). Estimates for the Hawaiian stock range from 550-790 to 2,100 (Rice and Wolman 1979, unpub. manuscript, submitted to IWC Scientific Committee; Baker et al. 1986; Darling and Morowitz 1986). The wide range of estimates is likely due to differences in analysis of mark and recapture data and survey techniques. Until more data are available, these estimates should be used with considerable caution (Table 1).

Minimum counts based on the total number of unique individuals identified over a specified period of time have also been developed. These range from 521 individuals for one year in 1981, to 922 over 4 years from 1977 to 1981 (Darling and Morowitz 1986). Perry et al. (1988) identified 1,140 unique individual humpback whales over a 9-year period (1977-1985) for the Central and eastern North Pacific. These counts do not account for mortality or recruitment and should not be considered abundance estimates.

Estimates for the wintering stocks in Mexico and the western Pacific are as yet unavailable, though numbers have been speculated to be in the hundreds or less. During the winter and spring of 1986, more than 100 individual humpbacks were photographically identified in waters

Table 1. Humpback whale abundance estimates -- Hawaii and the North Pacific.

Method	Count or Estimate	Time Frame	Area	Source
Photo-I.D. Minimum Count	1140	1977-1985	E.N. Pacific	Perry et al. 1988
	635	1977-1985	Hawaii	
	521 922	1981 1977-1981	Hawaii Hawaii	Darling and Morowitz 1986
Modified Bernoulli Estimate	1000	1981	Hawaii	Darling and Morowitz 1986
	2100	1977-1981	Hawaii and E.N. Pacific	
Petersen Estimate	1627 (± 307)	1977-1983	Hawaii	Baker et al. 1986
Weighted Petersen Estimate	1407 (± 294)	1980-1983	Hawaii	Baker and Herman 1987
Vessel Survey	550-790	1976-1979	Hawaii	Rice and Wolman 1979 (unpub.)
Aerial Survey	900 (± 150)	1985	Hawaii	Forestell (in press)

around Isla Socorro and Isla Isabel off Mexico, indicating a larger population than previously believed (Urban and Aguayo 1987). In the late winter of 1988, 15 humpback whales were identified, including at least 3 with new calves, in the Bonin Islands south of Japan. Five humpback whales were photographed in 1987, but not seen in 1988, resulting in a total of 20 iden-

tified individuals. A rough estimate of abundance based on available information indicates a population "at least in the low hundreds" for this area (Darling and Ford 1988). There is no current information regarding abundance of humpback whales from the other western North Pacific wintering areas off the Mariana Islands, Ryukyu Islands, and Taiwan.

DISTRIBUTION

Migration

In Australia, Dawbin (1966) found that humpback whales do not require coastal conditions for migration. Migration routes could not be related consistently to the direction of ocean currents, the nature of water masses, or bottom topography.

Humpback whales begin arriving in Hawaiian waters as early as October, though the season is more commonly thought of as beginning in December. Baker et al. (1985) reported a minimum known migration time of 79 days between Alaska and Hawaii based on resighting data. A peak in relative numbers of whales occurs in February (Herman, Forestell, and Antinaja 1980; Forestell, in press). Baker and Herman (1981) found that from 1977 to 1979 the Island of Hawaii showed the earliest peak influx of whales, with islands to the northwest showing progressively later dates of peak residency. Most whales depart by the end of April, though a few may stay through early June (Herman, Forestell, and Antinaja 1980).

The average duration of wintering in Hawaii for either sex of any age class is unknown. Glockner-Ferrari and Ferrari (1985) reported a maximum known cow-calf residency interval in Hawaii of 56 days. Dawbin (1966) found a succession in the migration to colder waters by different segments of the population, with an early departure of females without calves. In Hawaii, females with calves tend to be the last to leave the wintering grounds (Herman, Forestell, and Antinaja 1980).

Seasonal Habitats and Stock Structure

Individual whales wintering in Hawaii have been identified in the Gulf of Alaska (Kodiak Island, Prince William Sound, and Yakutat Bay), southeastern Alaska (Darling and

McSweeney 1985; Baker et al. 1986), and the Farallon Islands off California (Baker et al. 1986) during the summer. While humpback whales have been observed in southeastern Alaska in all months of the year, no one individual has yet been documented to overwinter or stay year-round (Straley, in press). Two individuals have also been identified wintering in Hawaii during one year and in Mexico in another year (Darling and McSweeney 1985; Baker et al. 1986). Darling and McSweeney (1985) suggest that, because of these migratory connections, all humpback whales in the eastern North Pacific are of the same stock. Baker et al. (1986) also propose that humpback whales in the eastern and central North Pacific are of one stock and form several geographically isolated feeding herds. These authors define the term "structured stock" as several feeding herds that intermingle to breed on one or more wintering grounds.

HABITAT USE

In general, humpback whale distribution in Hawaii appears to be limited to the 100-fathom (183 m) isobath and shallower waters. (Figure 2).

Surveys in the late 1970's (Wolman and Jurasz 1977; Rice and Wolman 1979, unpubl. manuscript submitted to IWC Scientific Committee; Herman, Forestell, and Antinaja 1980) showed that humpback whales prefer certain areas over others in Hawaii. The area of greatest use was found to be the four-island area (Maui, Molokai, Lanai, Kahoolawe) and Penguin Bank. Also heavily utilized were the Island of Niihau and the Island of Hawaii, Keahole Point north to Upolu Point (Figure 3). Kauai, Oahu, and the eastern and southwestern waters of the Island of Hawaii received substantially less usage. Kaula Island, just southwest of Niihau appears to mark the western limit of humpback whale distribution in Hawaii, as few animals have been reported around the atolls,

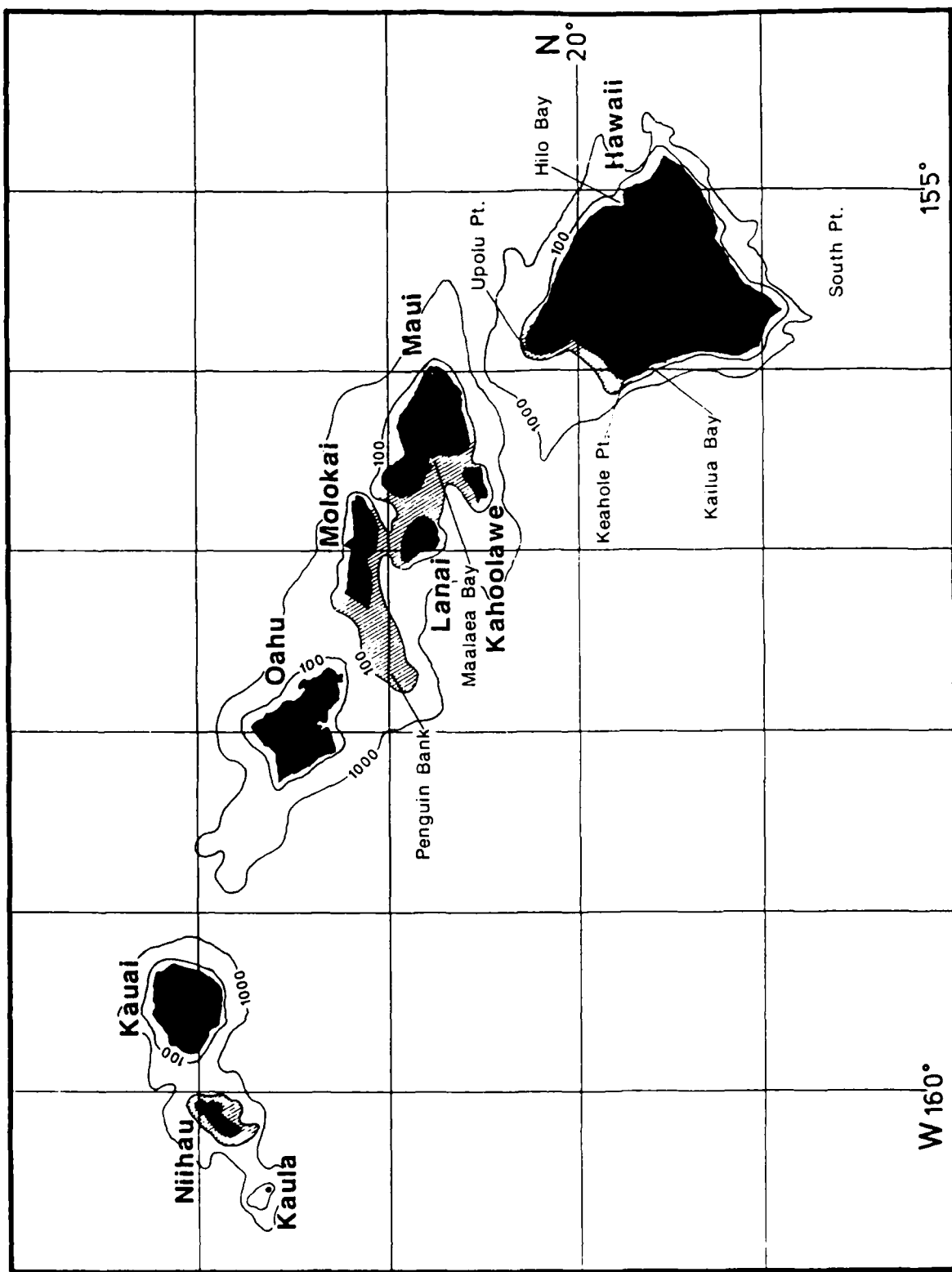


Figure 3. Areas of reported high density of humpback whales (depths in fathoms).

islands, banks, and reefs of the northwestern Hawaiian Islands. Although all-island surveys have not been undertaken since 1979, indications are that this general usage pattern has remained fairly consistent. Fluctuations in relative abundance within and between islands occasionally occur.

Humpback whales are known to use the waters of Hawaii to nurse their young. In addition, calving, courtship, and mating are thought to occur in or near Hawaii, though confirmed sightings of these behaviors have not been observed to date. Aggressive male-male competition for sexually mature females, including cows with calves, is evident throughout the season in Hawaii (Baker and Herman 1984). Cows with newborn calves are commonly found throughout the winter, and general areas of high usage by these pairs have been observed. Herman, Forestell, and Antinofa (1980) defined the north coast of Lanai as an area of high cow-calf density. Hudson (1978) suggested Maalaea Bay, Maui, as a major nursery area. Glockner-Ferrari and Ferrari (1985) characterized the southwest coast of Maui from MacGregor Point to Kaanapali as an area of high-calf use. Forestell (in press) found roughly three times as many total calves in the four island area as over Penguin Bank during aerial surveys.

ENVIRONMENTAL REQUIREMENTS

Humpback whales are strongly migratory, though routes between winter calving areas and summer feeding grounds are not well known. Humpback whales occur very close to shore and appear to be relatively sedentary once they arrive at their northern or southern seasonal destination (Leatherwood et al. 1982). Because of this behavior, they appear to have specific environmental requirements more closely associated with land masses than do any other species of large whales with the exception of the

gray whale (*Eschrichtius robustus*). Humpback whales also are affected by human activity to a greater degree than other balaenopterids.

Water Depth

The distribution of humpback whales during winter is almost exclusively over relatively shallow banks. Winn, Edel, and Taruski (1975) found that 99% of the sightings of humpback whales in the West Indies are found on banks between the 10- and 100-fathom (18 and 183 m) line. Whitehead and Moore (1982) narrow this down further by stating that humpback whales in the West Indies principally winter in waters between 15 and 60 m deep.

The same affinity for banks occurs in humpback whales wintering in Hawaiian waters (Figure 3). Wolman and Jurasz (1977) found that of 373 whales sighted in Hawaiian waters, only 7 were in deep interisland channels or in water deeper than 92 m. In a subsequent vessel survey, Rice and Wolman (1979, unpub. manuscript submitted to the IWC Scientific Committee) sighted only 2 out of 411 humpback whales in waters deeper than 180 m. Tinney (1988) states that whales in Hawaii tend to favor water about 25 fathoms (46 m) in depth.

Off windward Oahu, adult humpback whales have been observed on several occasions swimming slowly parallel to but just seaward of the 10-fathom (18 m) isobath where a sharp sea bottom escarpment drops from 10 to approximately 15 fathoms (18 to 27 m) (J. Naughton, Southwest Region, National Marine Fisheries Service, Honolulu, pers. obs.). The whales appear to follow the depth contour as they migrate along the coastline.

Glockner-Ferrari and Ferrari (1985) report that of the mothers and calves they recorded off Maui in 1977 and 1979, 80.3% were within the 10-fathom (18 m) curve. Glockner and Venus (1983) found mothers and calves

resting in shallow waters often just beyond the surf line. In a study in Maalaea Bay, Maui, by Muller, Carini, and Hudnall (1980 unpub. manuscr., Maui Whale Research Institute), most whales were observed in water 25 to 73 m deep. The only calves seen were in water estimated to be less than 18 m deep. High cow-calf densities relative to other age classes of whales at specific sites off the west coast of the Island of Hawaii have also been noted. These areas include waters shallower than 50 fathoms (91 m) between Keahole Point and Kiholo Bay, and from Keahuolu Point to Kailua Bay (M. Smultea 1988, Moss Landing Marine Laboratory, pers. commun.; E. Mathews and D. McSweeney 1988, West Coast Whale Research Foundation, pers. commun.). Compared with other age/sex classes of the population, the data indicate that mothers and calves prefer shallower waters. Cows with newborn calves tend to segregate themselves from other whales as well as from other cows and calves. This suggests that females with calves need substantial areas of shallow water in which to swim, rest, and presumably nurse (Tinney 1988).

Bank Characteristics

A. Size

In addition to water depth, the size of the bank appears to be of importance to humpback whales on their wintering grounds. Winn, Edel, and Taruski (1975) found that in West Indies waters, coasts with narrow shelves, generally less than 2 miles wide, do not harbor humpback whales. In contrast, the broad bank area of Silver and Navidad Banks contains the greatest concentration of humpback whales in the West Indies.

Similarly, in Hawaii Rice and Wolman (1979, unpubl. manuscr. submitted to IWC Scientific Committee) found by far the greatest number of whales on the Molokai-Lanai-Maui-Kahoolawe bank, a large shallow bank area gen-

erally surrounded by these four islands but also including Penguin Bank. They found the greatest concentration of whales, with 0.78 whale per square mile, on Penguin Bank, the largest single bank area in the main Hawaiian Islands. The second most important area was the Island of Hawaii, particularly the northwest coast where an expanded bank occurs between Upolu Point and Keahole Point. Other coastal areas surrounding the Island of Hawaii are bordered by a narrow shelf, with the exception of an expanded bank in Hilo Bay and at Ka Lae (South Point). Both these areas have yielded consistently high humpback whale counts (Figure 3).

In American Samoa a small number of humpback whales, including cows with calves, are sighted each year from July through October in the waters surrounding Tutuila Island. The bank surrounding Tutuila is especially broad off Cape Taputapu and Leone Bay. These areas yield the most sightings each year (J. Naughton, Southwest Region, National Marine Fisheries Service, Honolulu, pers. obs).

B. Leeward versus Windward

From December through March in Hawaiian waters, northeast trade winds are present about 55% to 65% of the time. These northeast trades result in generally consistent wind and wave action on windward coasts. Winds from the south and occasionally from the north account for the remainder of the wind and swell patterns (Herman 1979).

Rice and Wolman (1979, unpubl. manuscr. submitted to IWC Scientific Committee) found far more whales on the leeward side of the Hawaiian Islands than on the windward side. However, when calculated on the basis of whales per unit area, there was little difference between the two sides. They concluded that the greater abundance of whales on the leeward side appears to be due mainly to its larger areas of shallow water rather

than due to any marked preference by the whales for calmer waters. In fact, the single greatest density of whales was found on Penguin Bank (0.78 whale per square mile), an exposed bank area noted for its rough water.

Herman, Forestell, and Antinaja (1980) also noted that Penguin Bank is regularly exposed to strong, gusty trade winds, but is highly preferred humpback whale habitat. They found that windward areas of some Hawaiian Islands are not used much by whales, but this may reflect the limited extent of shallow water available and not the prevailing wind conditions. Herman (1979) concluded that there seemed to be no consistent relationship between wind or swell patterns and habitation by humpback whales.

In Australia, sheltered waters of the Great Barrier Reef between lat. 16°-21°S appear to be important breeding grounds for the East Australian humpback whale stock. However, there is evidence of humpback whales giving birth prior to reaching Great Barrier Reef waters (Paterson and Paterson 1984).

In the Bonin Islands, humpback whales including cows with new calves were found in the usually rough waters surrounding the islands. The islands are not high enough to create any significant lee, which is essentially nonexistent (Darling and Ford 1988).

C. Substrate

Very little work has been done on substrate characteristics of the banks where humpback whales are consistently found during the winter months. It is believed that humpback whales feed little, if at all, during winter (Matthews 1937; Chittleborough 1965; Dawbin 1966; Whitehead and Moore 1982). Therefore, the importance of substrate in attracting or supporting prey species does not appear to be a consideration.

Whitehead and Moore (1982) found the highest humpback whale song densities on Silver Bank in areas with virtually flat bottoms. Lowest song densities occurred where the bottom profile was rough, indicating coral growth. They concluded that there is evidence that singers select areas with smooth bottoms in the West Indies, thereby enhancing sound transmission.

No comparative analysis has been done for substrate preference in the Hawaiian Islands. However, bank areas with the highest concentration of whales (Penguin Bank, four-island area) are known for broad expanses of flat, sandy bottom as can be seen from bathymetric charts.

Surface Temperature

Whitehead and Moore (1982) found that humpback whales winter in the West Indies in waters of 24° to 28° C. They suspect that the warm waters are favorable for calving since the calves are born with a thin blubber layer. In the Southern Hemisphere Dawbin (1966) found that humpback whales winter in water temperatures of about 25° C.

In the Hawaiian Archipelago, sea-surface temperatures show relatively small seasonal and year-to-year changes, having a long-term average yearly range of 23.2° to 26.4° C (Seckel and Yong 1970). Surface temperatures during the winter in Hawaiian waters range between 23.2° and 24.2° C. These temperatures are slightly cooler than those found in other known humpback whale winter habitats.

The lack of sightings of humpback whales in the Northwestern Hawaiian Islands may be due to low sea-surface temperatures in the area. Huge bank areas occur there (i.e. Necker Island, Maro Reef, Gardner Pinnacles, Neva Shoal around Lisianski Island, French Frigate Shoals) and would seem to have

the desired characteristics; yet humpback whales are rarely sighted in these areas. Confirmed sightings have been made at Nihoa Island (A. Everson, Southwest Fisheries Center, National Marine Fisheries Service, Honolulu, pers. commun. and photos), and mothers and calves have been sighted at French Frigate Shoals (K. Kenyon, Seattle, WA., and J. Naughton, Southwest Region, National Marine Fisheries Service, Honolulu, pers. obs). However, aerial surveys specifically conducted to locate humpback whales in the northwestern Hawaiian Islands have found none (Herman, Forestell, and Antinaja 1980). The slightly cooler water in this more northerly segment of the Hawaiian Archipelago may preclude the use of these large banks as significant wintering areas by humpback whales.

Surface Salinity

In the Hawaiian Archipelago, maximum salinity occurs in November-February when the 35⁰/oo salinity isopleth has moved south to lat. 17°-19°N (Uchida and Uchiyama 1986). Therefore, the surface salinity in the humpback whale wintering environment in Hawaiian waters is between 35⁰/oo and 35.2⁰/oo. Considering the low salinity found in much of the humpback whales' summer feeding grounds, it is improbable that salinity plays a major role in selection of wintering areas.

Surface Currents

Most areas of the Hawaiian Archipelago have a net surface current flow to the west. However, flows are modified by the shapes of the islands causing large eddies to form downstream. Close to shore, tides have a major influence on currents. In many coastal areas of Hawaii, a rotary semidiurnal tidal current is present, usually varying in direction and speed. The bank areas of importance to humpback whales are influenced mainly by tidal currents. The strength of these currents can vary

from 3.0 to 32.5 cm/sec (Uchida and Uchiyama 1986).

Early studies in Hawaii suggested a general movement of humpback whales south to north through the main Hawaiian Islands in the winter (Baker and Herman 1981). Whales were thought to enter winter habitat at the Island of Hawaii and work through the main islands, departing later in the season at Oahu. The net current flow would support this hypothesis. However, Darling and Morowitz (1986) recently have shown that a few animals travel from Maui to Hawaii (north to south) in one season and suggest that the majority of the humpback whale population was present at least through the peak season (January - April). This would indicate some exceptions to the general trend and that surface currents may not play a major role in movement of humpback whales, at least within the Hawaiian Archipelago.

Turbidity

In considering the turbidity levels of glacial runoff waters and the generally nutrient rich conditions which comprise the humpback whales' summer feeding habitat, turbidity would not appear to have a negative environmental impact on whales in the wintering grounds. However, a number of observations have been made of humpback whales avoiding turbid coastal waters in Hawaii (Glockner-Ferrari and Ferrari 1985). During 1980, they reported that agricultural runoff from heavy winter storms created a dense mudline in nearshore waters, which the whales seemed to avoid. It was believed this may be a potentially important impact to the humpback whale population in Hawaii (Glockner-Ferrari and Ferrari 1985). Adult humpback whales have been observed swimming in clear water parallel to a meandering band of turbid, sediment-laden water from land runoff in the area of La'au Point, Molokai. They appeared to avoid swimming into the turbid water by changing direction

(J. Naughton, Southwest Region, National Marine Fisheries Service, Honolulu, pers. obs.). However, it is not known whether whales avoid these waters due to turbidity or to chemical pollutants from upland sources.

IMPACTS

Coastal Development

Known humpback whale habitat may be affected by harbor and boat ramp construction, nearshore resort development, alternative energy development, wastewater discharge and outfall construction, permanent vessel moorings, agricultural runoff, and recreational water sports. Water-dependent construction activities by themselves result in highly visible primary impacts such as blasting, dredging, and filling which may result in displacement, injury, and mortality. However, these adverse impacts can be reduced or eliminated through seasonal timing or construction design modifications, and the actual physical loss of habitat is small in comparison to the total available. It is the secondary and tertiary impacts associated with the initial habitat modification, such as increased vessel traffic associated with harbors, ramps, moorings and hotels, that may likely have irreversible consequences on the distribution and reproductive success of humpback whales.

Water quality degradation resulting from increased sewage effluent, surface runoff (agricultural, industrial, and residential), and the leaching of vessel hull anti-fouling compounds (e.g. tributyltin) may also adversely affect the distribution and physical well-being of humpback whales using nearshore waters. Untreated sewage dumped from vessel holding tanks and pumped from municipal outfalls during periods of overflow, such as storms and plant malfunctions, are sources of many infectious agents, viral, bacterial, and mycotic, to

which cetaceans have shown a definite susceptibility (Dailey 1985; J.P. Schroeder 1988, Naval Oceans Systems Center, Kaneohe, HI, pers. commun.). The long-term effects of low concentrations of compounds such as tributyltin on larger vertebrates such as whales is not known.

Vessel Traffic

In Hawaii, humpback whales are subject to physical and acoustic disturbance by large numbers of recreational boaters as well as an increasing number of whale-watching vessels as they engage in water skiing, parasailing, jet skiing, high speed pleasure cruising, and whale watching. At present, commercial shipping and commercial fishing vessel traffic do not appear to pose a significant problem in Hawaiian waters because of the location of their activities, and/or their routes and behavior.

The Navy occasionally conducts vessel firing exercises off Kahoolawe Island. During a test to determine in-water source levels of naval gunfire and humpback whale vocalizations, it was found that ambient noise was dominated by humpback whale phonations (Friedl and Thompson 1981).

Normal whale behavior (the energetic and often acrobatic behavior associated with pod formation and disassociation and competitive activities, such as breaching and peduncle or fluke slapping), in some instances, is indistinguishable from reactions to vessels and makes the effects of vessel traffic in Hawaii difficult to evaluate. Recent studies, however, have provided some insight into this problem. Bauer and Herman (1986) found humpback whales off Maui to significantly alter behaviors in response to vessels within 1,000 m. Increases in dive times and some threat behaviors were observed. Short-term impacts of reduced fitness resulting from excessive energy expenditure

during the nonfeeding season were suggested. They postulated that these probable short-term impacts are linked to the potential for long-term negative effects such as displacement, reduced reproductive success, and reduced recruitment.

Glockner-Ferrari and Ferrari (1985, 1987) note a continuing decline in the percentage of cow-calf pairs sighted in nearshore waters off west Maui. In their early studies, they found 80.3% of the mothers and calves observed were within the 10-fathom (18 m) isobath. However, this percentage has steadily decreased, with a low in 1983 of 17.2% within the 10-fathom (18 m) isobath. In 1984 and 1985, the percentages again declined to 14.1 and 5.7%, respectively (Glockner-Ferrari and Ferrari 1987, Table 2). They attribute fewer whales being observed in nearshore waters to human activities, such as direct interactions between whales and vessels, and displacement by high-speed vessel operations. They also believe that habitat is being lost through the effects of pollution and report a decrease in water quality resulting from agricultural runoff from coastal development and sewage output.

Other recent studies also strongly indicate that humpback whales may be abandoning coastal habitat because of human activities. Herman, Forestell, and Antinaja (1980) noted a preference of humpback whales for subregions removed from areas of dense human habitation or activity. On the basis of aerial surveys, they observed an absence of whales within 5- to 6-km of Lahaina, Maui, and suggested that whales avoided the area because of human activities, primarily recreational boat traffic. Forestell (in press) also noted a lack of sightings in the Lahaina area relative to other areas off Maui. In addition, he found virtually no whales during aerial surveys within a 5- to 6-km radius around the new small boat ramp and protective breakwater at Keawakapu, Maui. He hypothesizes that whales, in fact, may be in these areas, but because of increased vessel traffic, they engage in behaviors that make them less obvious, such as remaining submerged for longer periods, or that more noticeable large pods of whales or cow-calf pairs may selectively avoid the area. Single animals, which typically remain underwater for longer periods, may be present in these areas yet be missed by aerial surveys.

Table 2. Percentage of mothers and calves sighted in nearshore waters off West Maui (from Glockner-Ferrari and Ferrari 1987).

Year	Ocean Hours of Observation (No.)	Mother-Calf Sightings (No.)	Mother-Calf Sets Within 0.4 km of Shore (No.)	Mother-Calf Sightings (%)
1977	174	39	25	64.1
1978	150	48	42	87.5
1979	134	47	37	78.7
1980	291	53	15	28.3
1981	228	52	17	32.7
1982	251	69	18	26.1
1983	233	63	11	17.5
1984	283	78	11	14.1
1985	282	88	5	5.7

Tinney (1988) lists and describes activities potentially affecting humpback whales in coastal waters of Hawaii. He states that these activities, occurring often enough, densely enough, or long enough in or near areas traditionally used by humpback whales may cause them to abandon or avoid the areas and possibly result in increased mortality and/or decreased reproduction.

Specific activities (from Tinney 1988), not in any particular order of importance, which potentially affect humpback whales include the following:

1. Swimming, snorkeling, and diving
2. Surfing
3. Wind and motorized surfing
4. Waterskiing
5. Kayaking
6. Recreational fishing
7. Commercial fishing
8. Sailing
9. Jetskiing
10. Addictor boating (rental mini-hydroplanes)
11. Parasailing
12. Whale watching
13. Scientific research
14. Marine transport
15. Water taxis
16. Surface warship operations
17. Submarine operations

18. Aircraft overflights
19. Marine construction

The effect of acoustic interference on "singing" and other related behaviors and its eventual impact on reproductive activities are not well known. "Singers," however, have been observed to stop singing when high speed or very loud vessels transited nearby (Bauer and Herman 1986).

At present, with the exception of the potential loss of summer foraging habitat, the continued loss and degradation of known preferred winter habitat in Hawaiian waters, particularly that of mothers and calves, probably constitutes one of the major threats to the recovery of the Hawaiian population of humpback whales. In order to better gauge the prospects for and encourage recovery of this endangered species in Hawaii, habitat requirements and reproductive parameters for humpback whales in Hawaiian waters need to be more precisely defined. Further, a cost-effective and accurate means of determining population trends and a method of assessing the status of humpback whales in Hawaiian waters must be developed and initiated so that additional protective measures and recovery actions can be implemented should they be required.

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